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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 10-84

UNMANNED EVALUATION OF THE U.S. NAVY MK 15 AND A MODIFIED MK 15 (MK 15 1/2) CLOSED CIRCUIT UBA

JAMES S. KEITH

AUGUST 1984

NAVY EXPERIMENTAL DIVING UNIT

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
PANAMA CITY, FLORIDA 32407

IN REPLY REFER TO:

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MK 15 1/2	canister duration
closed circuit	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Navy Experimental Diving Unit (NEDU) performed unmanned testing on a U.S. Navy MK 15 and modified MK 15 closed-circuit (C/C) underwater breathing apparatus (UBA) using a hyperbaric breathing simulator. The purpose of these tests was twofold: (1) to evaluate breathing resistance/breathing work characteristics of the MK 15 and modified MK 15 UBAs using a variety of mouthpiece and hose configurations and (2) to evaluate carbon dioxide (CO_2) absorbent canister duration for the modified MK 15 UBA at a depth of 50 feet-of-seawater (FSW) in a wide range of water temperatures.

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Breathing resistance/breathing work studies were made using five different mouthpiece and hose configurations at depths to 150 FSW at simulated work rates ranging from light to extreme. CO_2 canister duration tests were conducted in water temperatures ranging from 29 to 90°F.

The modified MK 15 UBA (MK 15 1/2) was equipped with the following changes effecting rig performance: (1) a MK 16 UBA center section providing increased scrubber capacity and better thermal protection and (2) the Rexnord prototype mouthpiece with the larger diameter MK 16 hoses.

Results of these unmanned performance tests revealed that:

a. MK 15 breathing resistance/breathing work can be significantly lowered by use of either the AGA/Alternately Closed Semi-Closed (ACSC) hose and mouthpiece assembly or the Rexnord prototype mouthpiece and MK 16 hose assembly vice the standard Scott mouthpiece.

b. The MK 15 UBA when used in conjunction with the Redar hoses (wire wound, non collapsible) and Scott mouthpiece combination exhibited improved breathing resistance/breathing work over the standard MK 15 hoses.

c. The MK 15 1/2 breathing resistance/breathing work was the lowest of the configuration tested, providing significant improvement over the MK 15 with standard Scott mouthpiece.

d. The MK 15 1/2 CO_2 absorbent canister provides an average increase of 40% in canister duration life in unmanned tests compared to the MK 15 UBA (reference 1) over the range of water temperatures tested.

Special

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Table of Contents

Glossary

ACSC	alternating closed/semi closed circuit
BPM	breaths per minute
C/C	closed-circuit
Canister Breakthrough	point at which CO_2 concentration in the inhaled gas reached 0.50 percent surface equivalent
°C	temperature degrees Centigrade
cmH_2O	centimeters of water pressure
CO_2	carbon dioxide gas
EDF	Experimental Diving Facility Hyperbaric Chamber Complex
°F	temperature degrees Fahrenheit
FFM	full-face mask
FSW	feet-of-seawater
HP	high pressure
HP SODASORB	high-performance SODASORB
ID	inside diameter
$kg.m/\ell$	kilogram-meters per liter (respiratory work)
ℓpm	liters per minute (flow rate)
MOD	modified
NAVSEA	Naval Sea Systems Command
NEDU	Navy Experimental Diving Unit
N_2-O_2	nitrogen-oxygen gas mix
O_2	oxygen gas
ΔP	pressure differential
PO_2	partial pressure of oxygen
psid	pounds per square inch differential
psig	pounds per square inch gauge
RMV	respiratory-minute-volume in liters-per-minute

Glossary (continued)

SCUBA	self-contained underwater breathing apparatus
SDV	swimmer delivery vehicle
SEV	surface equivalent value
SI	*System International (units of measure)*
TEMP	temperature
Texp	exhaled gas temperature
TV	the liter-tidal volume of air breathed in and out of the lungs during normal respiration
UBA	underwater breathing apparatus
U/W	underwater

SI Unit Conversion Table

To Convert From	To	Multiply By
kg.m/ℓ	joule per liter (J/L)	9.807
psi	kilopascal (kPa)	6.895
°C	kelvin (K)	°K = °C + 273.15
°F	kelvin (K)	°K = (°F + 459.67)/1.8
FSW	meters of seawater (MSW)	0.305
FSW	kilopascal (kPa)	3.065

Abstract

The Navy Experimental Diving Unit (NEDU) performed unmanned testing on a U.S. Navy MK 15 and modified MK 15 closed-circuit (C/C) underwater breathing apparatus (UBA) using a hyperbaric breathing simulator. The purpose of these tests was twofold: (1) to evaluate breathing resistance/breathing work characteristics of the MK 15 and modified MK 15 UBAs using a variety of mouthpiece and hose configurations and (2) to evaluate carbon dioxide (CO_2) absorbent canister duration for the modified MK 15 UBA at a depth of 50 feet-of-seawater (FSW) in a wide range of water temperatures.

Breathing resistance/breathing work studies were made using five different mouthpiece and hose configurations at depths to 150 FSW at simulated work rates ranging from light to extreme. CO_2 canister duration tests were conducted in water temperatures ranging from 29 to 90°F.

The modified MK 15 UBA (MK 15 1/2) was equipped with the following changes effecting rig performance: (1) a MK 16 UBA center section providing increased scrubber capacity and better thermal protection and (2) the Rexnord prototype mouthpiece with the larger diameter MK 16 hoses.

Results of these unmanned performance tests revealed that:

a. MK 15 breathing resistance/breathing work can be significantly lowered by use of either the AGA/Alternately Closed Semi-Closed (ACSC) hose and mouthpiece assembly or the Rexnord prototype mouthpiece and MK 16 hose assembly vice the standard Scott mouthpiece.

b. The MK 15 UBA when used in conjunction with the Redar hoses (wire wound, non collapsible) and Scott mouthpiece combination exhibited improved breathing resistance/breathing work over the standard MK 15 hoses.

c. The MK 15 1/2 breathing resistance/breathing work was the lowest of the configuration tested, providing significant improvement over the MK 15 with standard Scott mouthpiece.

d. The MK 15 1/2 CO_2 absorbent canister provides an average increase of 40% in canister duration life in unmanned tests compared to the MK 15 UBA (reference 1) over the range of water temperatures tested.

KEY WORDS: UBA
MK 15
MK 15 1/2
closed circuit
breathing resistance
breathing work
canister duration

I. INTRODUCTION

During February and March 1984 NEDU tested the MK 15 UBA and a modified MK 15 (MK 15 1/2) for breathing resistance/breathing work with various mouthpiece and hose combinations to determine how improvement in performance of its breathing loop could be accomplished. A wire wound, non-collapsible hose providing substantially increased durability was evaluated with the Scott mouthpiece to determine its relative performance. In addition, MK 15 1/2 CO_2 absorbent canister life was evaluated to increase the data available on UBA canister performance. This testing was conducted in response to MK 15 Configuration Control Board inputs stating the requirement for: (1) longer canister durations in cold water (6 hours at 29°-40°F), (2) a mouthpiece and hose combination providing decreased breathing resistance and greater comfort and (3) breathing hoses with increased durability.

Unmanned testing was conducted in the NEDU Experimental Diving Facility (EDF). The UBAs were evaluated with respect to breathing work and breathing resistance at simulated diver work rates ranging from light to extreme using five mouthpiece and hose combinations listed in TABLE 1 and illustrated in APPENDIX B (Figures 1 through 5). In addition, the MK 15 1/2 UBA was tested to determine the duration of its CO_2 absorbent canister at a variety of water temperatures ranging from 29°F to 90°F at 50 FSW.

II. FUNCTIONAL DESCRIPTION (Figure 7)

The MK 15 is a closed circuit rebreather capable of providing approximately 595 liters (21 cu. ft.) of both O_2 and a breathable diluent gas.

During normal operation, the diver inhales a mixture of O_2 and diluent gas and the diver's exhaled gas is recirculated back to the scrubber housing where it is filtered through the scrubber and CO_2 is removed.

As the diver descends, the MK 15 adds diluent to maintain the volume of the diver's breathing loop. Diluent gas is added to the breathing loop in response to actuation of the diluent addition valve by the motion of the molded neoprene diaphragm as a result of the reduced volume in the breathing loop.

While the diver is working at his assigned depth, his PO_2 is monitored by the three O_2 sensors and maintained at 0.70 ± 0.10 ATA. When the diver's PO_2 goes below a predetermined set-point, the sensors send a signal to the O_2 addition valve, via the electronics assembly, which opens to allow additional O_2 into the breathing loop. Oxygen addition continues until the PO_2 in the breathing loop is brought back to the predetermined set-point. A second signal is then sent by the electronics assembly causing the O_2 addition valve to close.

The primary display indicates relative oxygen concentration and qualitative electronics status. The primary display is mounted on the divers right arm and indicates the PO_2 in the breathing loop by means of status lights. Functional indications are: Normal O_2, High O_2 (0.8 ATA), Low O_2 (0.6 ATA) and transition from one state to another, low battery voltage and/or failure of components.

<u>TABLE 1</u>

Mouthpiece and Hose Configurations Tested

A. MK 15 UBA with standard hoses and Scott mouthpiece (Figure 1).

B. MK 15 UBA with Redar hoses and Scott mouthpiece (Figure 2).

C. MK 15 UBA with AGA/ACSC hoses and mouthpiece (Figure 3).

D. MK 15 UBA with Rexnord prototype mouthpiece and MK 16 hoses (Figure 4).

E. MK 15 1/2 UBA with Rexnord prototype mouthpiece and MK 16 hoses (Figure 5).

<u>NOTE</u>: All CO_2 absorbent canister duration tests were conducted using the MK 15 1/2 (Figure 5).

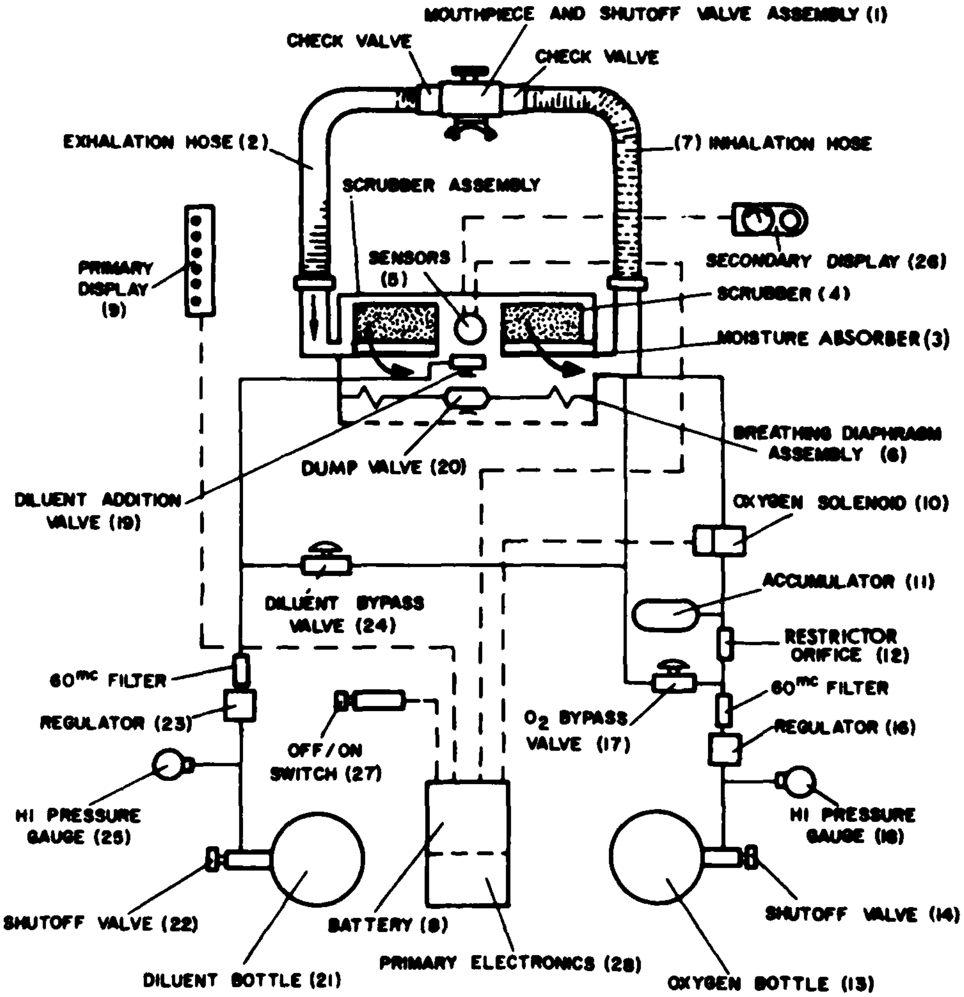


Figure 7. MK 15/MK 15 1/2 Functional Block Diagram

The diver is also equipped with a secondary display which directly monitors the O_2 sensors and the secondary battery level. The secondary display consists of an analog meter which is powered independently. The manual bypass valves permit the diver to control the addition of diluent or O_2 to the breathing loop should the automatic system fail.

The modified MK 15 (MK 15 1/2) is functionally identical to the MK 15 UBA. The modifications are listed in TABLE 2 and illustrated in APPENDIX B (Figures 5 and 6). The principal changes effecting UBA performance characteristics are twofold: (1) The center section containing CO_2 scrubber, oxygen sensors and diaphragm, was replaced with a MK 16 UBA center section. The replacement center section is made principally of LEXAN, a plastic material providing improved thermal insulation of the CO_2 scrubber. The scrubber is larger, increasing the capacity of CO_2 absorbent material by approximately 10% and (2) the MK 15 1/2 is equipped with the Rexnord prototype mouthpiece and MK 16 breathing hoses each having a larger inside diameter (ID).

III. EQUIPMENT PHOTOS

APPENDIX B contains photos of the MK 15 and MK 15 1/2 mouthpiece and hose combinations tested (Figures 1 through 6).

IV. TEST PROCEDURE

A. Test Plan. Figure 8 illustrates the test equipment set-up. APPENDIX C provides the complete test plan and the test equipment illustrated in Figure 8 is listed in APPENDIX D. A breathing simulator and hyperbaric chamber simulated inhalation and exhalation at various depths and diver work rates. The wet box in which the UBA was submerged simulated the wide range of water temperatures in which the UBA might be used. A total of five respiratory minute volumes (RMV) were tested at all normal operating depths to simulate light through extreme diver work rates. Breathing resistance was measured using a pressure transducer located in the oral cavity of the mouthpiece.

B. Controlled Parameters

1. Breathing Resistance Tests - Breathing resistance controlled parameters included:

(a) Standardized NEDU breathing rates, tidal volume, exhalation/inhalation time ratio and breathing waveform were controlled as set forth in NEDU Report 3-81 (reference 2).

(b) UBA breathing gas: air.

(c) Depths: 0, 33, 66, 99, 132 and 150 FSW.

(d) Diluent supply pressure: 1000 psig.

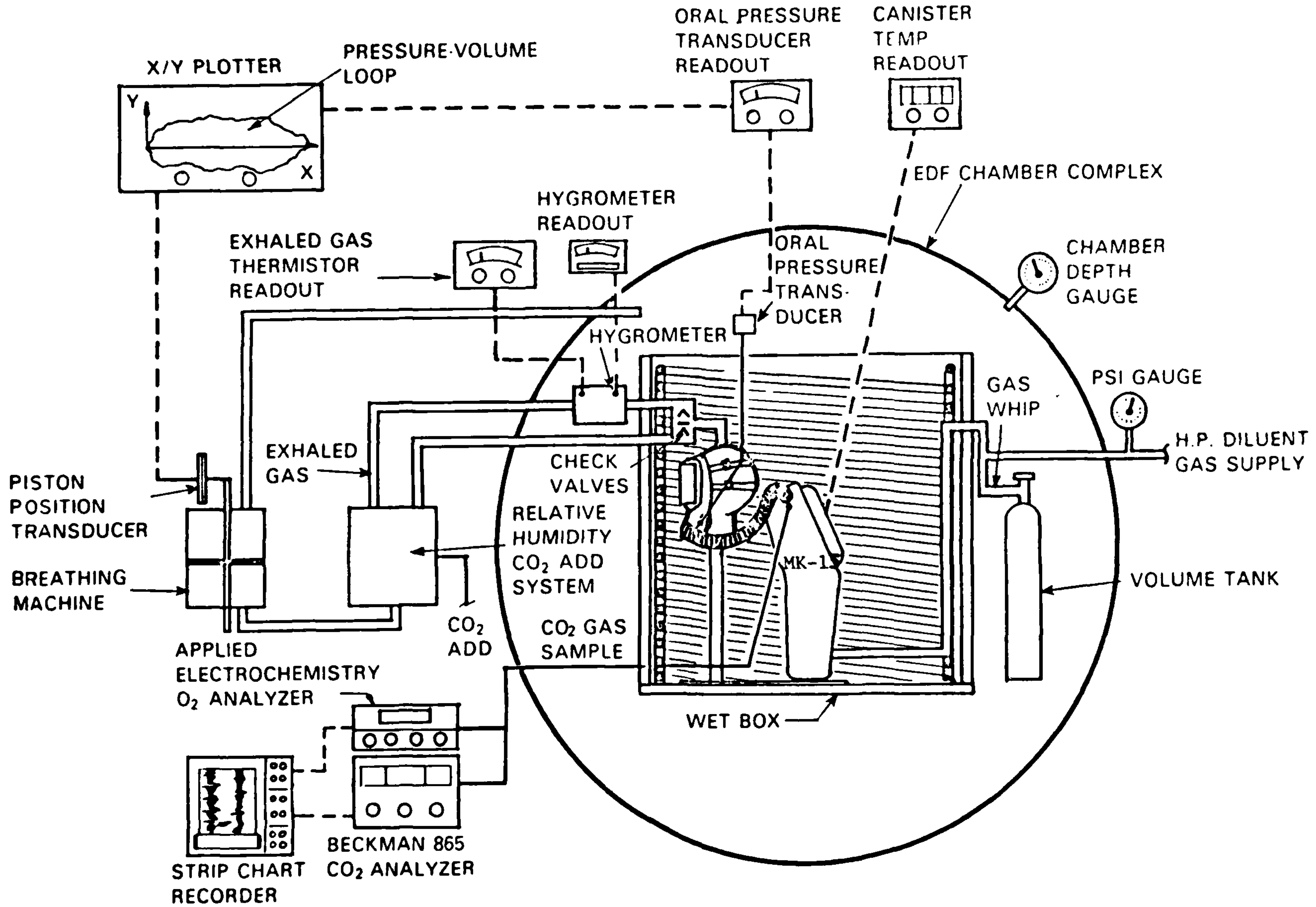


Figure 8. Test Setup

TABLE 2

MODIFICATIONS TO THE MK 15 COMPRISING THE MK 15 1/2

A. MK 16 UBA center section

1. Made of LEXAN offering better thermal insulation to canister bed.

2. Larger scrubber 10% increase in CO_2 absorbent material over MK 15.

3. Non metalic construction of center housing eliminates through water shorting problems encountered with MK 15 UBA.

B. MK 16 UBA hoses/Rexnord prototype mouthpiece

1. Increased ID.

2. Mouthpiece offers purge hole similar to Draeger LAR V.

C. Hard mounted regulators

1. Replace the two high pressure regulator hoses with stainless steel tubing.

D. MK 16 UBA style electronics assembly cover

1. The electronics assembly is equipped with a threaded cover and a second threaded ring to aid in opening the battery compartment.

E. New harness

1. Crotch strap is deleted.

2. Shoulder straps have quick disconnect buckles.

3. Shoulder and waist strap attach to side plates on lower portion of UBA.

F. Carrying handle installed

2. Canister Duration Tests -Canister duration controlled parameters included:

(a) Standardized CO_2 add rates and exhaled gas temperatures controlled as set forth in reference 2.

(b) UBA breathing gas: air.

(c) CO_2 absorbent: HP SODASORB with moisture content between 14.3 and 16.2%.

(d) Water TEMP: 90, 70, 55, 40, 35 AND 29°F.

(e) Relative humidity of exhaled gas: 90-95%.

(f) Depth: 50 FSW.

(g) Diluent supply pressure: 1000 psig.

(h) Canister packing density: Canister duration in any UBA is quite sensitive to how the absorbent is packed. Consequently, uniformity of canister packing was maintained at $\pm$ 4 ounces in order to achieve consistent results.

NOTE: In both breathing resistance/breathing work and CO_2 canister duration studies air was used as the breathing medium since its density and heat transfer properties are virtually identical to the N_2O_2 breathing mix normally used in the MK 15.

C. Measured Parameters

1. Breathing Resistance Tests - Maximum ΔP in cmH_2O (i.e. total pressure excursion between full exhalation and full inhalation cycles).

2. Canister Duration Tests: CO_2 level out of scrubber expressed as percentage of surface equivalent value (SEV).

D. Computed Parameters

1. Breathing Resistance Tests: Respiratory work per liter tidal volume measured in $kg \cdot m/\ell$ from ΔP vs volume plots. A typical pressure-volume plot is illustrated in Figure 9.

2. Canister Duration Tests: Exhaled gas TEMP was calculated and controlled as a function of water temperature based on the standardized procedure in reference 2.

E. Data Plotted

1. The following plots were developed from data obtained in the breathing resistance tests:

a. Peak exhalation to peak inhalation ΔP (cmH_2O) vs depth (FSW) at each RMV (ℓpm) tested.

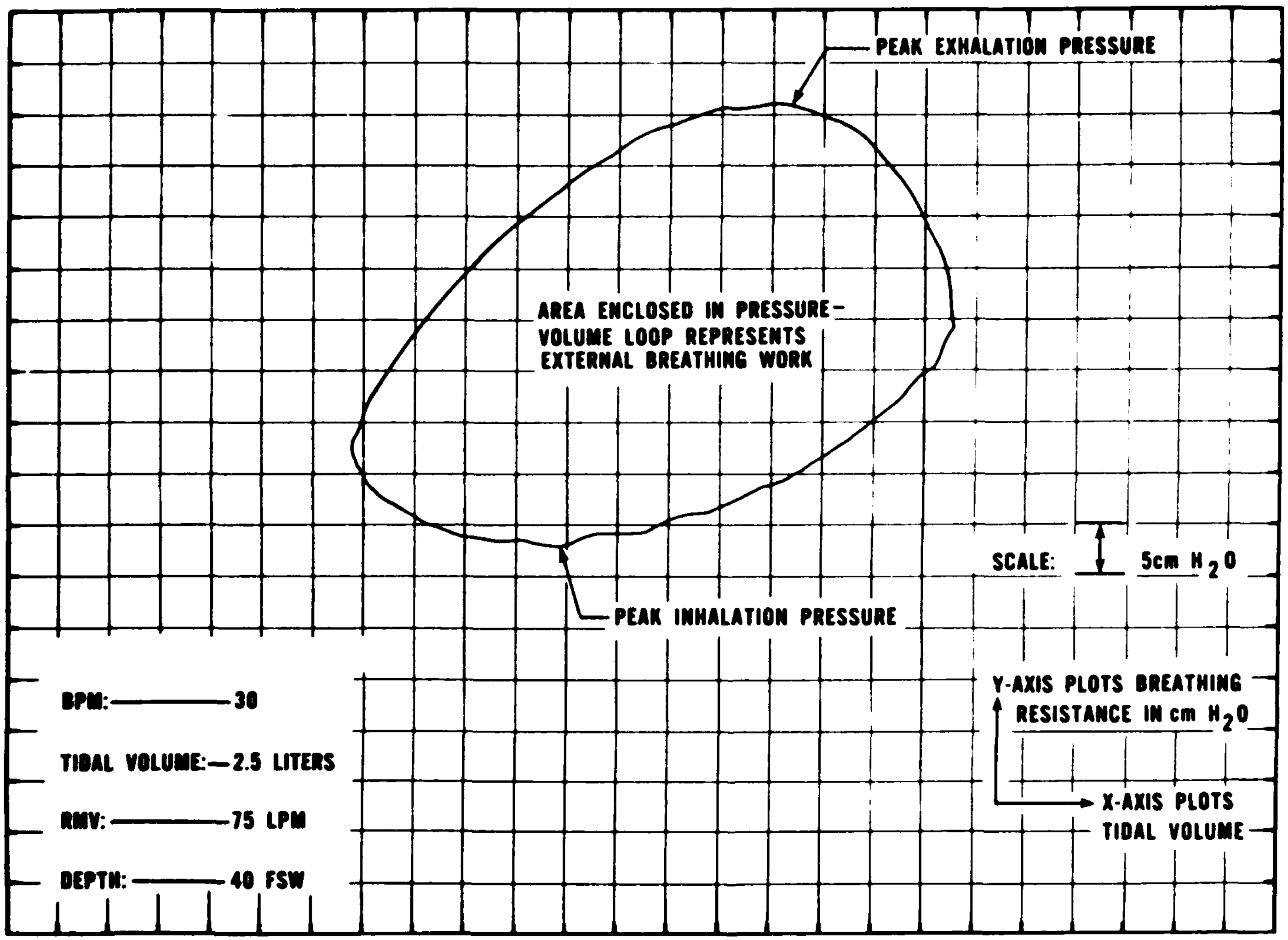


Figure 9. Pressure - Volume Loop Generated at 75 RMV at a depth of 150 FSW

b. Respiratory work per liter (kg·m/ℓ) vs depth (FSW) at each RMV (ℓpm) tested.

2. The following plots were developed from data obtained in the canister duration tests: canister effluent CO_2 (% SEV) vs time (min.).

V. RESULTS

A. Breathing Resistance and Breathing Work Tests. APPENDIX E (Figures 10 through 14) contains plots of peak differential breathing pressures vs depth and APPENDIX F (Figures 15 through 19) contains plots of breathing work vs depth for each equipment combination tested. Peak inhalation to peak exhalation in cmH_2O was measured at each RMV tested. Breathing work is measured in kg·m/ℓ and is also plotted at each RMV evaluated.

Breathing work is a measure of the respiratory energy expended by the diver to operate his UBA. When used in conjunction with breathing resistance data, it provides a useful tool in the evaluation of UBA. TABLE 3 provides a comparison of the peak differential pressures in each mouthpiece and hose combination tested at 150 FSW and 75 RMV while TABLE 4 provides a similar comparison of breathing work. The numbers in parenthesis in TABLES 3 and 4 represent the relative position in which that particular combination finished in each test (i.e., (1) would represent the best performance of the five combinations and (5) the worst).

B. CO_2 Absorbent Canister Duration Tests. A total of 6 canister duration tests were conducted as part of this evaluation series. All canister duration tests were conducted at 50 FSW with ambient water temperature being varied from 29 to 90°F. Because the MK 15 1/2 uses the MK 16 scrubber, test results were compared to MK 16 unmanned canister durations of reference 3. One run was made at each designated temperature, with no significant variation from reference 3 results. The canister durations at all temperatures are compared with MK 15 canister durations in TABLE 5.

Figure 20 is a sample of the type of CO_2 absorbent canister duration plots generated during unmanned testing. Rest and work cycles are readily observed as continuing for the duration of each test. APPENDIX G (Figure 21) plots only the mean % SEV CO_2 vs time generated during the work cycles in order to display the results of testing at all temperatures on one graph. The data on the graph is carried beyond 0.50% SEV CO_2 during work cycles to give a more complete picture of UBA performance.

VI. DISCUSSION

A. Breathing Resistance and Breathing Work Tests. NEDU Report 3-81, "Standardized NEDU Unmanned UBA Test Procedures and Performance Goals," (reference 2) establishes a performance goal of a total maximum breathing resistance of 22 cmH_2O and 0.18 kg·m/ℓ respiratory work at 75 RMV and maximum normal operating depth for C/C diver breath-driven UBA using air. This goal does not represent a minimum acceptable performance level. Rather, the goal when met by a UBA will insure that the UBA is not the limiting factor in diver performance.

TABLE 3

Comparison of Total Breathing Resistance
Peak Inhalation to Peak Exhalation
Breathing Pressures at 150 FSW and 75 RMV

UBA COMBINATION	PEAK TO PEAK DIFFERENTIAL BREATHING PRESSURE (cmH_2O)	
MK 15 w/Standard Hoses and Scott Mouthpiece	77.0	(5)
MK 15 w/Redar Hoses and Scott Mouthpiece	62.5	(4)
MK 15 w/AGA ACSC Mouthpiece and Hoses	36.5	(3)
MK 15 w/Rexnord Prototype Mouthpiece and MK 16 Hoses	34.0	(2)
MK 15 1/2 w/Rexnord Prototype Mouthpiece and MK 16 Hoses	29.5	(1)

NOTES:

a. NEDU Performance Goal: 0.18 kg·m/ℓ with peak to peak breathing pressures not exceeding 22 cmH_2O at 75 RMV and 150 FSW.

b. Numbers in parenthesis represent the relative position in which that equipment combination finished.

TABLE 4

Comparison of Breathing Work
at 150 FSW and 75 RMV

UBA COMBINATION	BREATHING WORK (kg·m/ℓ)	
MK 15 w/Standard Hoses and Scott Mouthpiece	0.542	(5)
MK 15 w/Redar Hoses and Scott Mouthpiece	0.423	(4)
MK 15 w/AGA ACSC Mouthpiece and Hoses	0.249	(3)
MK 15 w/Rexnord Prototype Mouthpiece and MK 16 Hoses	0.234	(2)
MK 15 1/2 w/Rexnord Prototype Mouthpiece and MK 16 Hoses	0.201	(1)

NOTES:

a. NEDU Performance Goal: 0.18 kg·m/ℓ with peak to peak breathing pressures not exceeding 22 cmH_2O at 75 RMV and 150 FSW.

b. Numbers in parenthesis represent the relative position in which that equipment combination finished.

TABLE 5

Unmanned Canister Duration Tests

Comparison of MK 15 and MK 15 1/2

WATER TEMP (°F)	MK 15 TIMES TO 0.5% CO_2 SEV (MIN)	MK 15 TIMES TO 1.0% CO_2 SEV (MIN)	MK 15 1/2 TIMES TO 0.5% CO_2 SEV (MIN)	MK 15 1/2 TIMES TO 1.0% CO_2 SEV (MIN)
29	175	218	286	336
35	197	233	275	330
40	211	252	297	346
55	225	273	308	346
70	265	290	317	347
90	225	290	325	357

Examination of the data presented in Tables 3 and 4 shows that none of the combinations tested met the established performance goal. However, manned testing as documented in reference 4 has proved that C/C O_2 UBA with performance similar to the MK 15 UBA in standard configuration will adequately support a working diver. Consequently, since the goals established in reference 2 are dynamic in nature, as more data is gathered, they will be updated to reflect the most recent and realistic performance requirements available.

The MK 15 1/2 exhibited the lowest breathing work and peak differential pressures measured during the evaluation. This is due to the large flow passages in the Rexnord prototype mouthpiece with MK 16 hoses and the larger inhalation and exhalation ports on the MK 16 center housing.

The performance of the AGA/ACSC and the Rexnord prototype mouthpiece with MK 16 hose configurations varied with depth and work rate. The Rexnord prototype has less breathing work/resistance at greater depths and higher work rates while the AGA/ACSC has lower breathing work/resistance at shallower depths and lesser work rates. This is probably due to the design of the mouthpieces. The AGA/ACSC has a slightly larger diameter opening on the inhalation and exhalation ports. However, the flow of gas is restricted by a baffle located in the middle of the mouthpiece. The Rexnord prototype has no internal baffles. The lower cost of the Rexnord prototype and MK 16 hoses (about 60% of the AGA/ACSC and Scott combinations) makes this combination a logical replacement for the Scott mouthpiece.

The wire wound, non collapsible Redar hoses performed better than the standard MK 15 hoses with both hose configurations using the Scott mouthpiece. These hoses provide a significant increase in durability and are ideal for use in close quarter operations where the likelihood of snagging or damaging a hose and causing rig flood-out are greatly increased.

Breathing work/peak differential pressure performance of the standard MK 15 UBA configuration is indicative of its mid 1960's design. As stated above however, manned testing (reference 4) has shown performance for UBA with these work and differential pressures to adequately support the working diver over the projected operational depth range 0-150 FSW.

B. CO_2 Absorbent Canister Duration Tests. The standard NEDU unmanned canister duration test scenario as described in APPENDIX C was conducted. This procedure simulates a diver resting in the water on a bicycle-ergometer for 4 minutes at a CO_2 production rate of 0.90 LPM and then working at an CO_2 production rate of 1.60 ℓpm for 6 minutes. This routine is alternated until the canister output reaches a minimum level of 0.50% SEV CO_2.

As demonstrated in Table 5 and Figure 21, performance of the MK 15 1/2 CO_2 absorbent canister's remained almost constant in water temperatures between 29 and 90°F. The design of the canister is similar to the MK 15 but the construction material has been changed to LEXAN which provides better thermal insulation in cold water. Large improvements over MK 15 CO_2 absorbent canister performance have been accomplished using the MK 16 UBA scrubber. An average 40% increase in canister durations to 0.50% SEV was observed over the full temperature range, with a low of 19% greater duration at 70°F and high of

63% greater duration at 29°F. Canister performance in cold water is hindered by the stainless steel construction of the MK 15 scrubber which rapidly transmits heat, vitally needed to sustain the reaction between CO_2 and the HP SODASORB, away from the absorbent bed and into the surrounding water.

C. MK 15 1/2 Modification. Some of the modifications to the MK 15 UBA that comprised the MK 15 1/2 do not affect UBA performance and were not tested. These include the MK 16 style electronics assembly cover, new harness and carry handle.

Initial manned dives were conducted using the MK 15 1/2 during the MK 16 table validation dive series at NEDU in April 1984. Additional manned dives are planned during the MK 16 Lazy Shot deployment procedures testing to be conducted in August and September 1984.

VII. CONCLUSIONS

A. Significant improvement in breathing work/peak differential pressure performance can be made to the MK 15 by using other hoses, mouthpieces, and canister types.

B. The Redar hoses have improved durability without increasing breathing resistance.

C. The MK 15 1/2 modification, including retrofit of the MK 16 canister, hoses and Rexnord prototype mouthpiece to the MK 15, provides the greatest improvement in breathing work/peak differential pressure performance of the modifications tested.

D. The average 40% improvement in CO_2 absorbent canister duration over the entire range of water temperatures evaluated provides a marked increase making the MK 15 1/2 modification a viable alternative for improved performance.

VIII. REFERENCES

1. NEDU Report 8-83, 'Unmanned Evaluation of the U.S. Navy MK 15 Closed Circuit UBA,' James R. Middleton, July 1983.

2. NEDU Report 3-81, 'Standardized NEDU Unmanned UBA Test Procedures and Performance Goals,' James R. Middleton and Edward D. Thalmann, CDR, MC, USN, July 1981.

3. NEDU Report 7-83, 'Unmanned Evaluation of USN MK 16 First Article Closed Circuit UBA,' James R. Middleton, July 1983.

4. NEDU Report 5-79, 'Evaluation of Modified DRAEGER LAR V Closed-Circuit Oxygen Rebreather,' James R. Middleton and Claude A. Piantadosi, August 1979.

APPENDIX A

List of Commercial Manufacturer's Addresses

Model: AGA ACSC Mouthpiece/Hoses

Manufacturer: AGA SPIRO AB
S-181 81 LIDINGO, Sweden
Telephone: 08-731-1211

Model: Redar Hoses

Manufacturer: R. E. Darling Co. Inc.
3749 Romero
Tucson, Arizona 85705

APPENDIX B

Equipment Photos

Figures 1 through 6

Figure 1. MK 15 with Standard Hoses

Figure 2. MK 15 with Redar Hoses and Scott Mouthpiece

Figure 3. MK 15 with AGA/ACSC Hoses and Mouthpiece

Figure 4. MK 15 UBA with Rexnord Prototype Mouthpiece and MK 16 Hoses

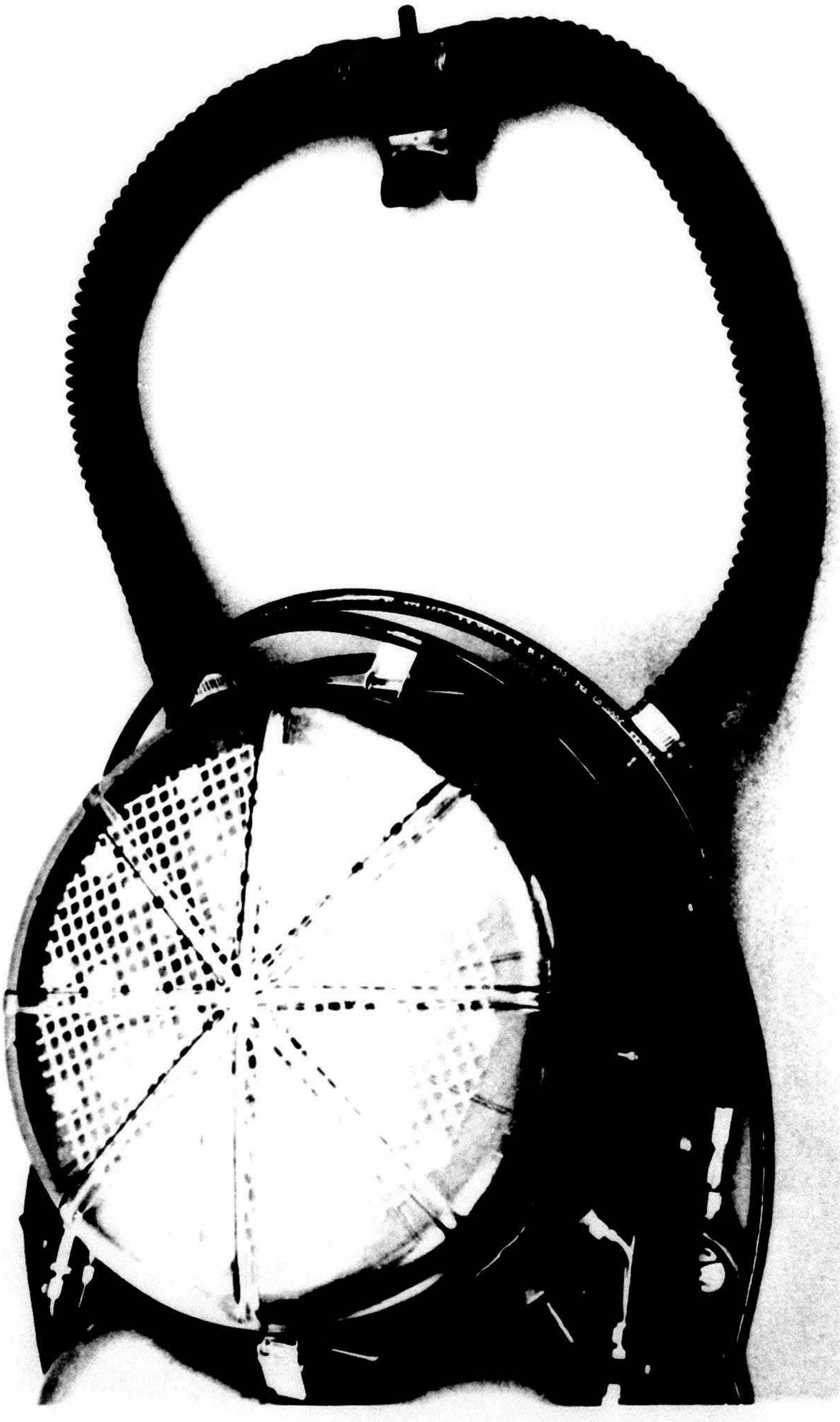


Figure 5. MK 15 1/2 UBA with Rexnord Prototype Mouthpiece and MK 16 Hoses

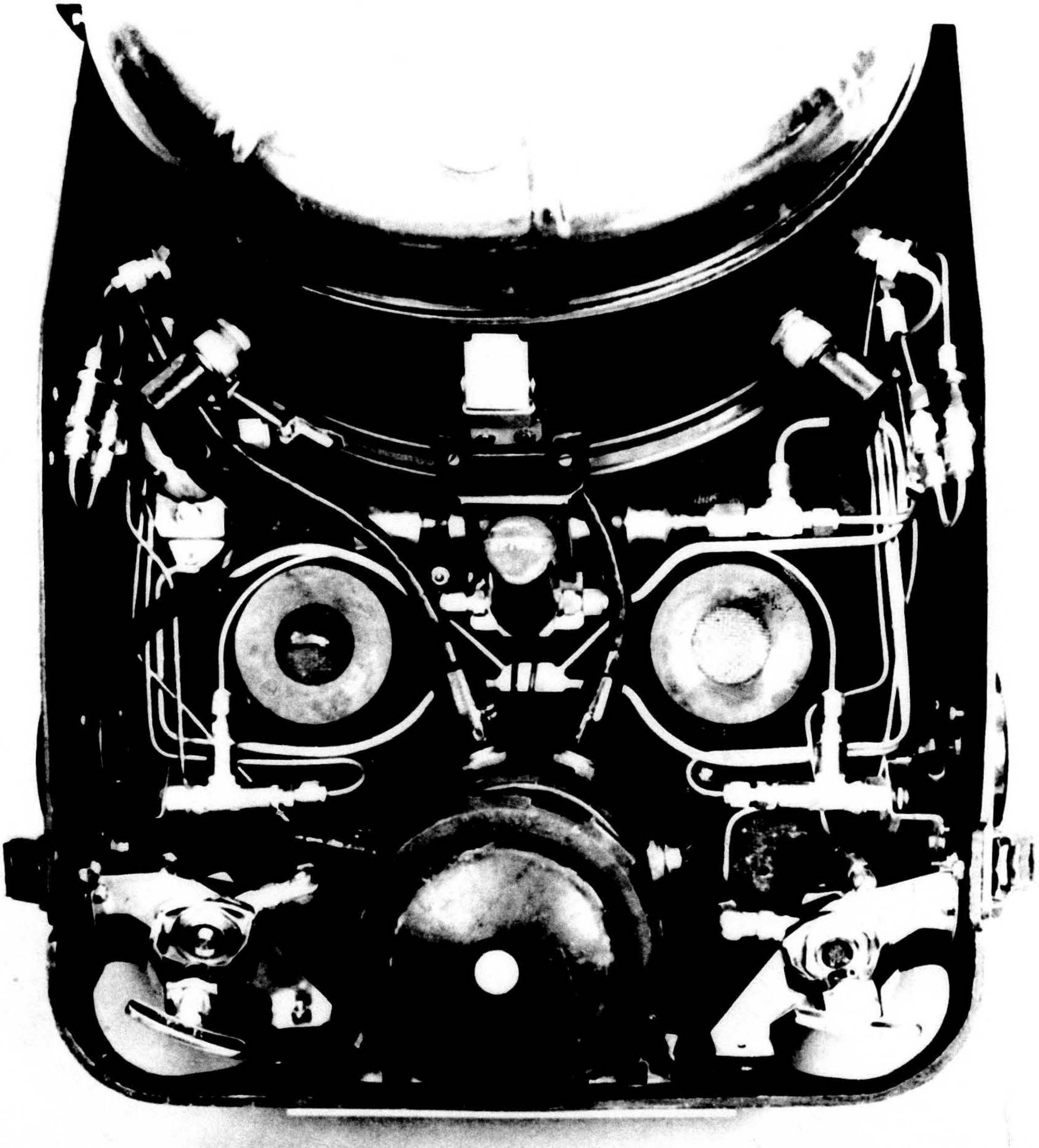


Figure 6. MK 15 1/2 UBA Showing Principal Modifications

APPENDIX C

Test Plan

A. Test Plan for Breathing Resistance Evaluation:

(1) (a) Insure that UBA is set to manufacturers specification and is working properly using HP SODASORB.

(b) Chamber on surface.

(c) Calibrate transducers.

(d) Open diluent gas supply valve to test UBA.

(e) Adjust breathing machine to 1.5 TV and 15 BPM and take data.

(f) Adjust breathing machine to 2.0 TV and 20 BPM and take data.

(g) Adjust breathing machine to 2.5 TV and 25 BPM and take data.

(h) Adjust breathing machine to 2.5 TV and 30 BPM and take data.

(i) Adjust breathing machine to 3.0 TV and 30 BPM and take data.

(j) Stop breathing machine.

(2) (a) Pressurize chamber to 33, 66, 99, 132 and 150 FSW.

(b) Repeat steps (1)(e) - (1)(j) at each depth.

(3) (a) Bring chamber to surface.

(b) Check calibration on transducers.

(4) Repeat steps (1)-(3) with other mouthpiece and hose assemblies, as applicable.

B. Test Plan for CO_2 Canister Duration Evaluation:

(1) (a) Insure that UBA is set to manufacturers specification and is working properly using HP SODASORB.

(b) Chamber on surface.

(c) Calibrate transducers and CO_2 analyzers.

(d) Open diluent gas supply valve to test UBA.

(e) Water TEMP to be approximately 90°F.

(f) Start humidity add system.

(g) Pressurize chamber to 50 FSW.

(h) Start CO_2 add and maintain following procedure until 1.0% SEV CO_2 is reached:

4 minutes at 0.9 ℓpm CO_2 add/2.0 TV and 11.5 BPM.
6 minutes at 2.0 ℓpm CO_2 add/2.0 TV and 25 BPM.

(i) Take data every 10 seconds to breakthrough.

(2) Repeat steps (1)(a) - (1)(i) at 70, 55, 40, 35 and 29°F, respectively.

APPENDIX D

Test Equipment

1. Breathing machine.

2. VALIDYNE DP-15 pressure transducer w/1.00 psid diaphragm (oral pressure) (1 ea).

3. Arc.

4. The EDF heating and cooling system will be used to control water temperature during the canister duration tests.

5. MFE Model 715M X-Y plotter.

6. VALIDYNE CD-19 transducer readout (1 ea).

7. External air supply pressure gauge.

8. Chamber depth gauge.

9. Test UBAs.

10. Breathing machine/piston position transducer/CO_2 and humidity-add system.

11. Relative humidity sensor.

12. Strip chart recorder.

13. Thermistor for exhaled gas TEMP (1 ea).

14. Thermistor for Arc water TEMP (1 ea).

15. DIGITEC HT-5820 thermistor readouts (2 ea).

16. BECKMAN/865 infrared analyzers for monitoring CO_2 out of the scrubber (2 ea).

APPENDIX E

Breathing Resistance Data

Peak inhalation to peak exhalation differential pressure vs depth is plotted for all five combinations tested.

KEY

Figure 10: MK 15 with Standard Hoses and Scott Mouthpiece

Figure 11: MK 15 with Radar Hoses and Scott Mouthpiece

Figure 12: MK 15 with AGA ACSC Hoses and Mouthpiece

Figure 13: MK 15 with Rexnord Prototype Mouthpiece and MK 16 Hoses

Figure 14: MK 15 1/2 with Rexnord Prototype Mouthpiece and MK 16 Hoses

FIG.10 PEAK TO PEAK DIFFERENTIAL PRESSURE VS. DEPTH
MK–15 WITH STANDARD HOSES AND SCOTT MOUTHPIECE

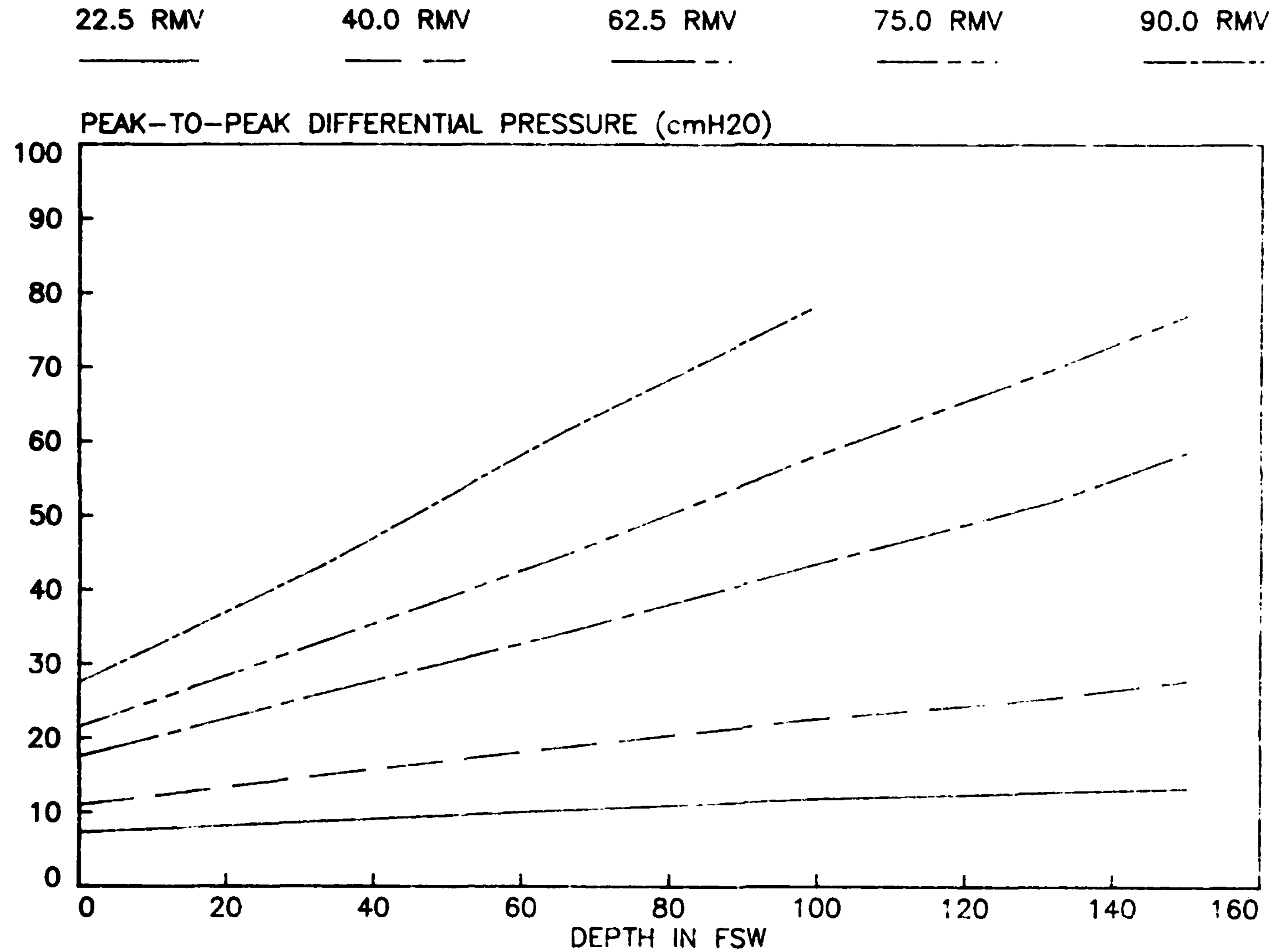


FIG.11 PEAK TO PEAK DIFFERENTIAL PRESSURE VS. DEPTH
MK−15 WITH REDAR HOSES AND SCOTT MOUTHPIECE

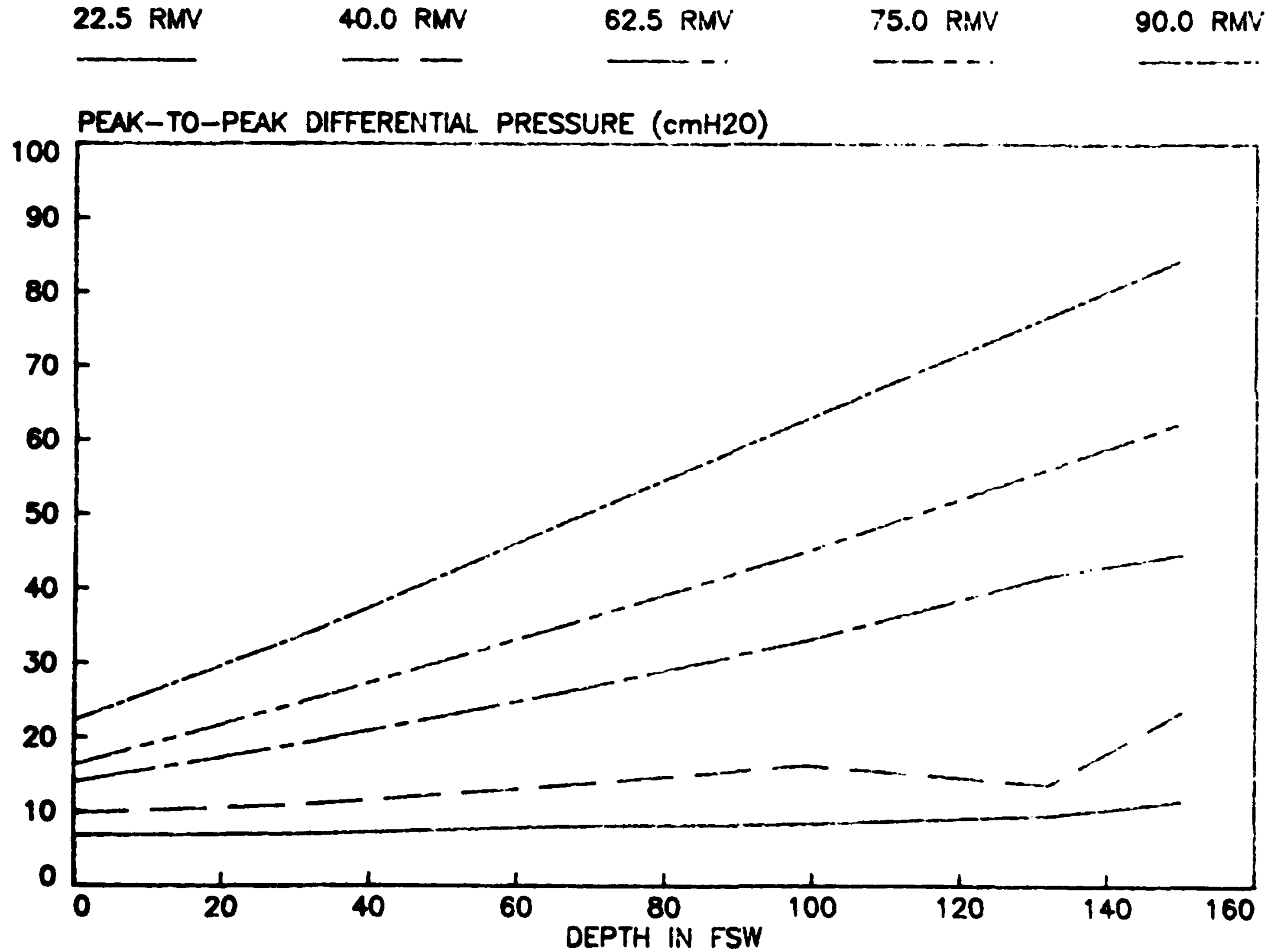


FIG.12 PEAK TO PEAK DIFFERENTIAL PRESSURE VS. DEPTH

MK—15 WITH AGA ACSC LARGE HOSES AND MOUTHPIECE

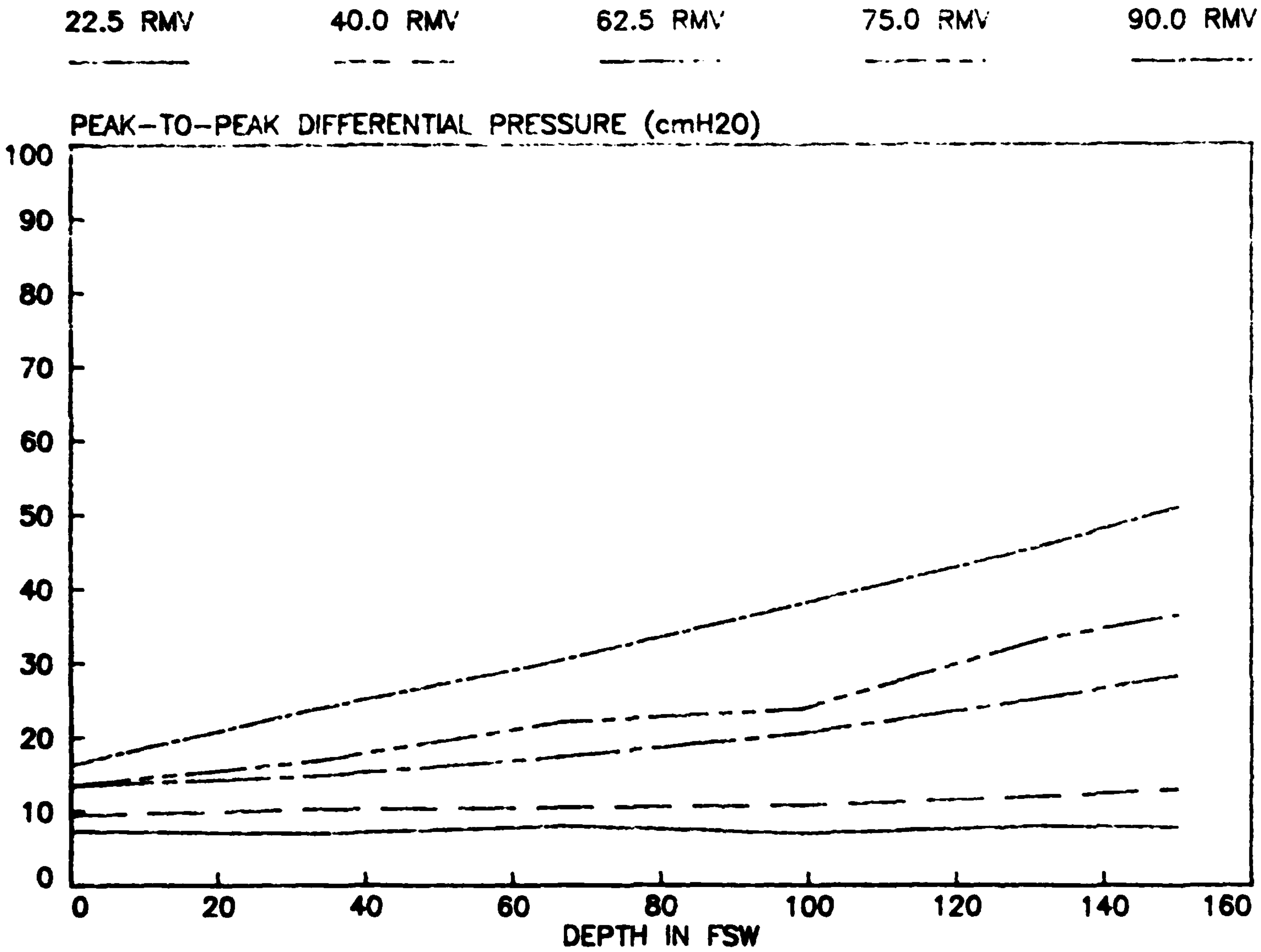


FIG.13 PEAK TO PEAK DIFFERENTIAL PRESSURE VS. DEPTH
MK−15 WITH REXNORD PROTOTYPE MOUTHPIECE & MK−16 HOSES

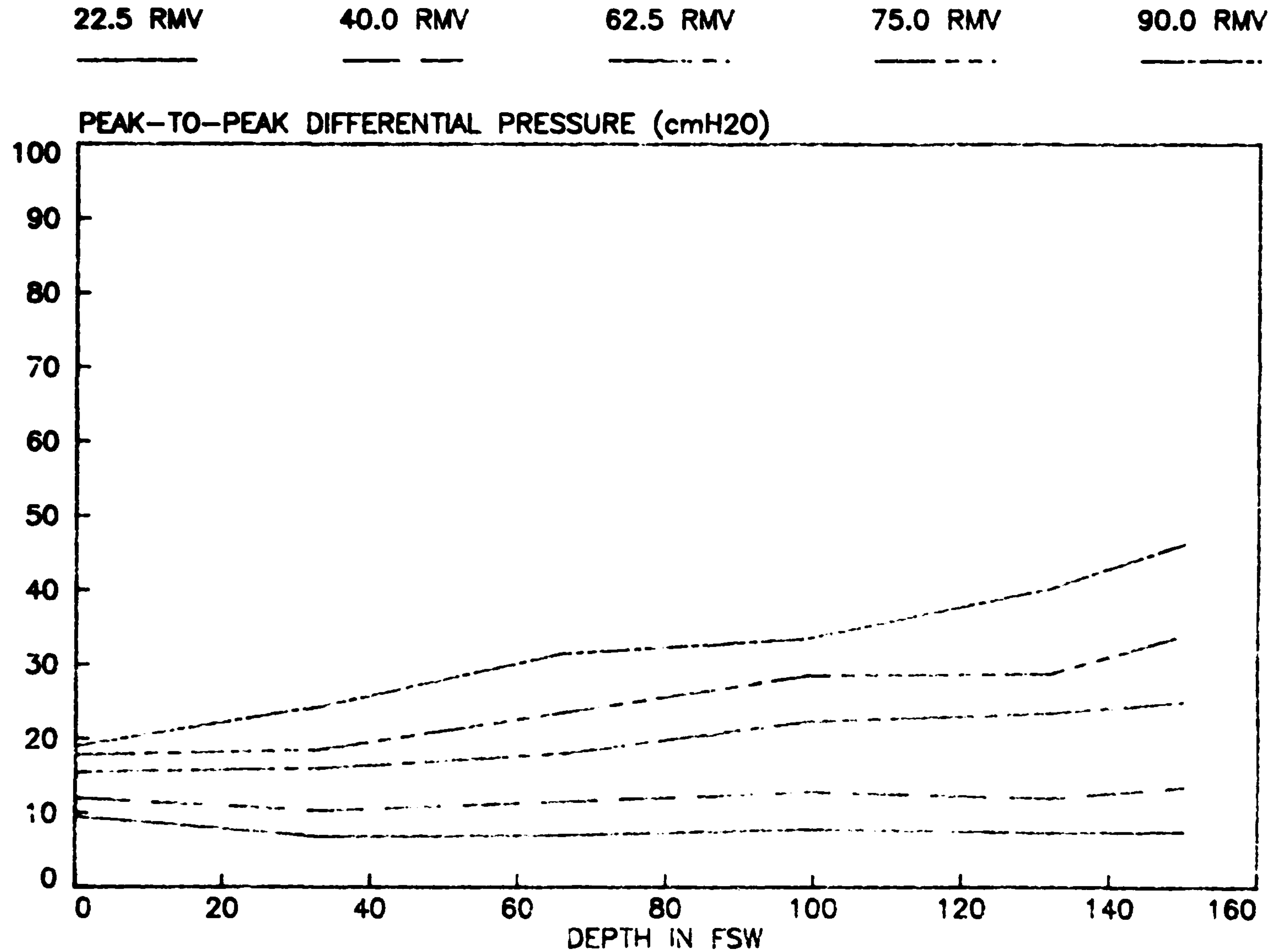
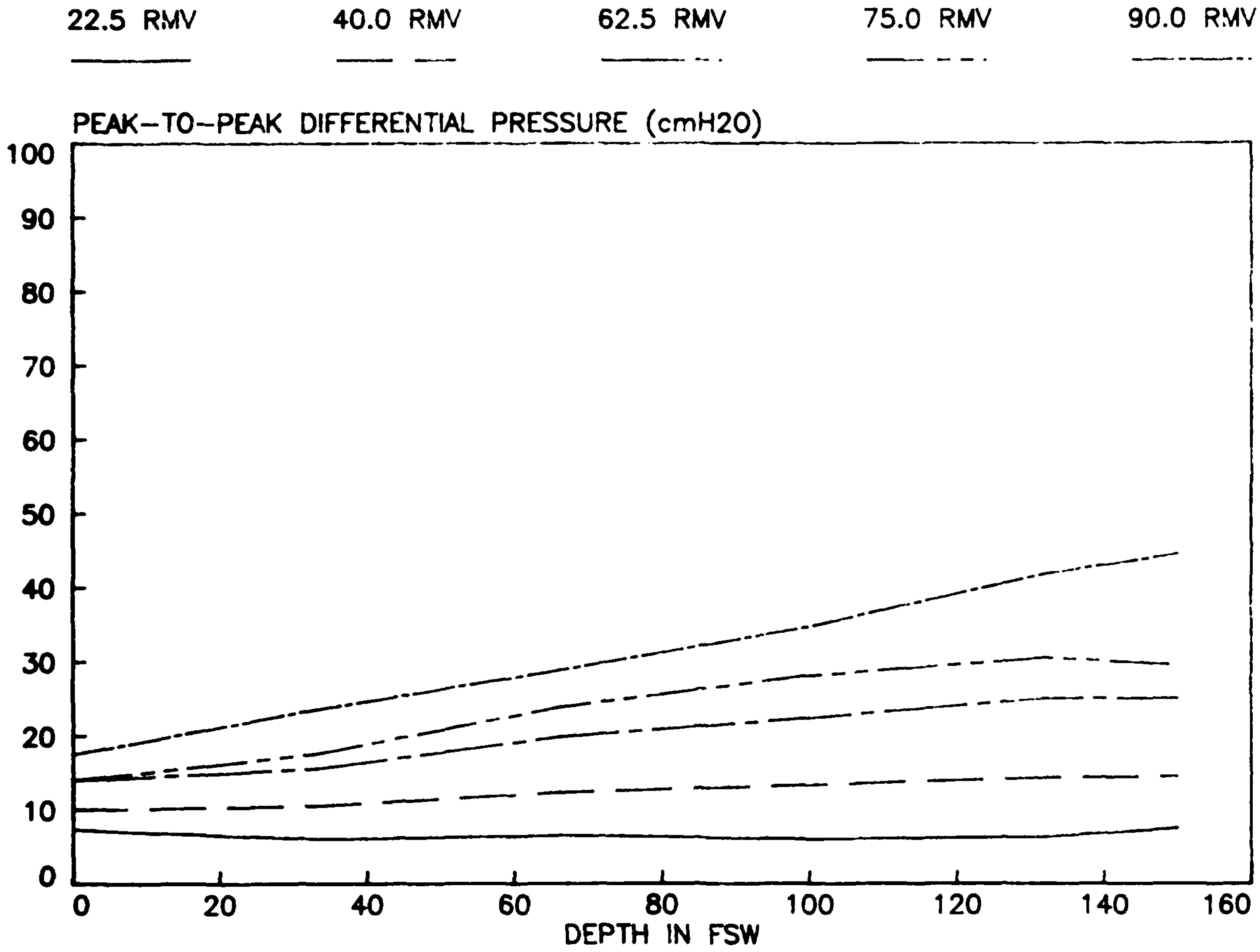


FIG.14 PEAK TO PEAK DIFFERENTIAL PRESSURE VS. DEPTH

MK–15 1/2 WITH REXNORD PROTOTYPE MOUTHPIECE & MK–16 HOSES



APPENDIX F

Breathing Work Data

Total breathing work vs depth at each RMV tested is plotted in this section.

KEY

Figure 15: MK 15 with Standard Hoses and Scott Mouthpiece

Figure 16: MK 15 with Redar Hoses and Scott Mouthpiece

Figure 17: MK 15 with AGA ACSC Hoses and Mouthpiece

Figure 18: MK 15 with Rexnord Prototype Mouthpiece and MK 16 Hoses

Figure 19: MK 15 1/2 with Rexnord Prototype Mouthpiece and MK 16 Hoses

FIG.15 BREATHING WORK VS. DEPTH

MK-15 WITH STANDARD HOSES AND MOUTHPIECE

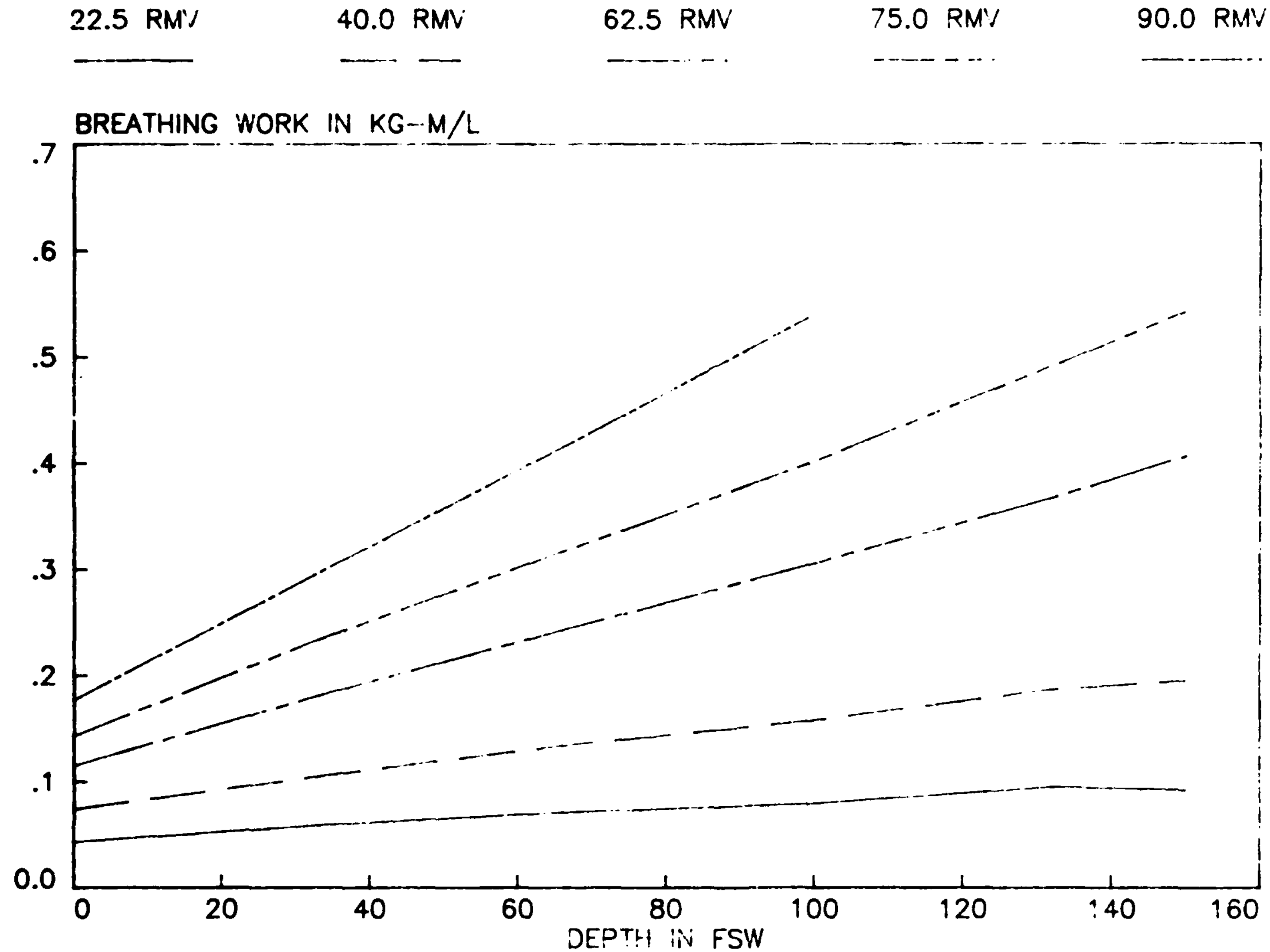


FIG.16 BREATHING WORK VS. DEPTH

MK—15 WITH REDAR HOSES AND MOUTHPIECE

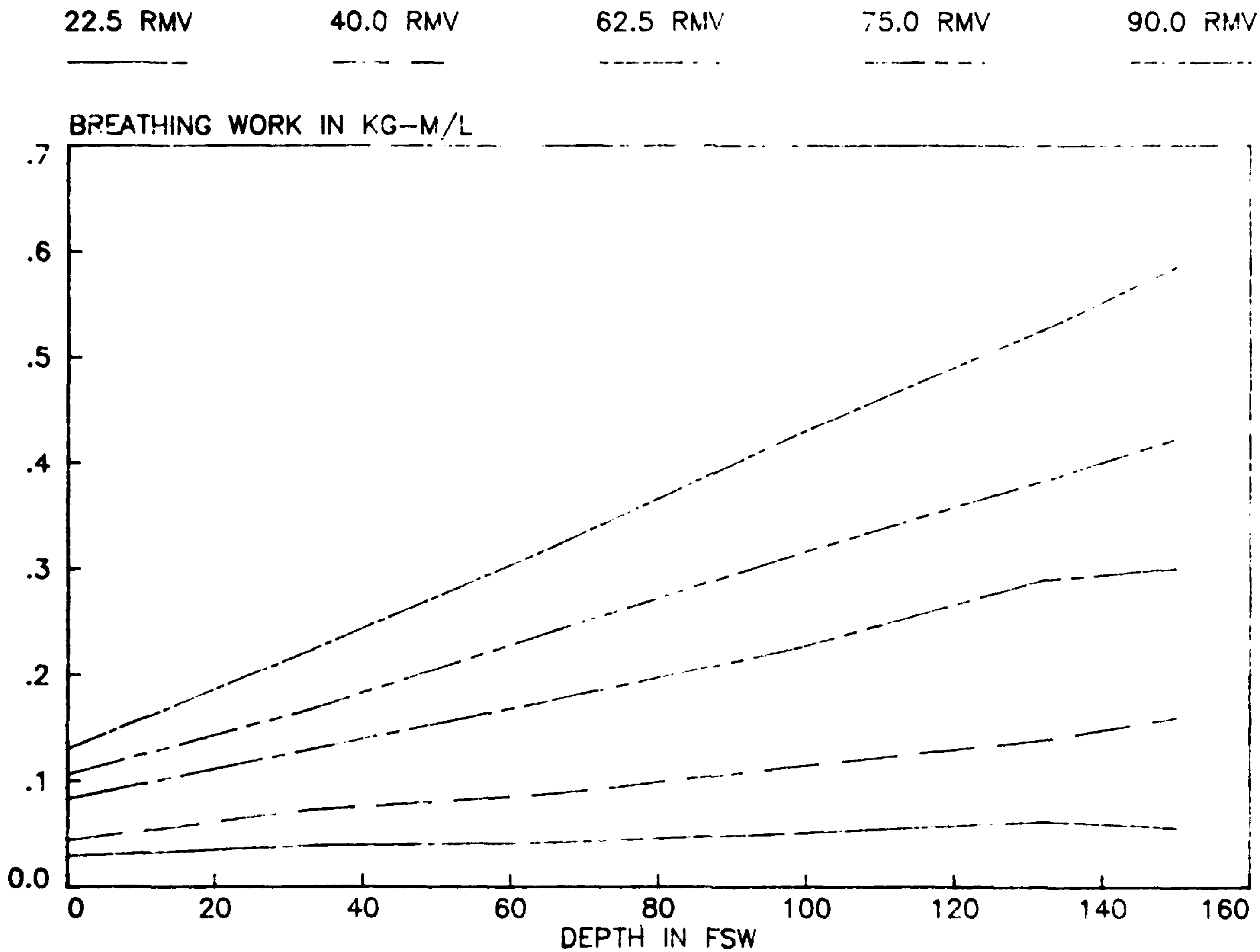


FIG.17 BREATHING WORK VS. DEPTH

MK-15 WITH AGA ACSC LARGE HOSES AND MOUTHPIECE

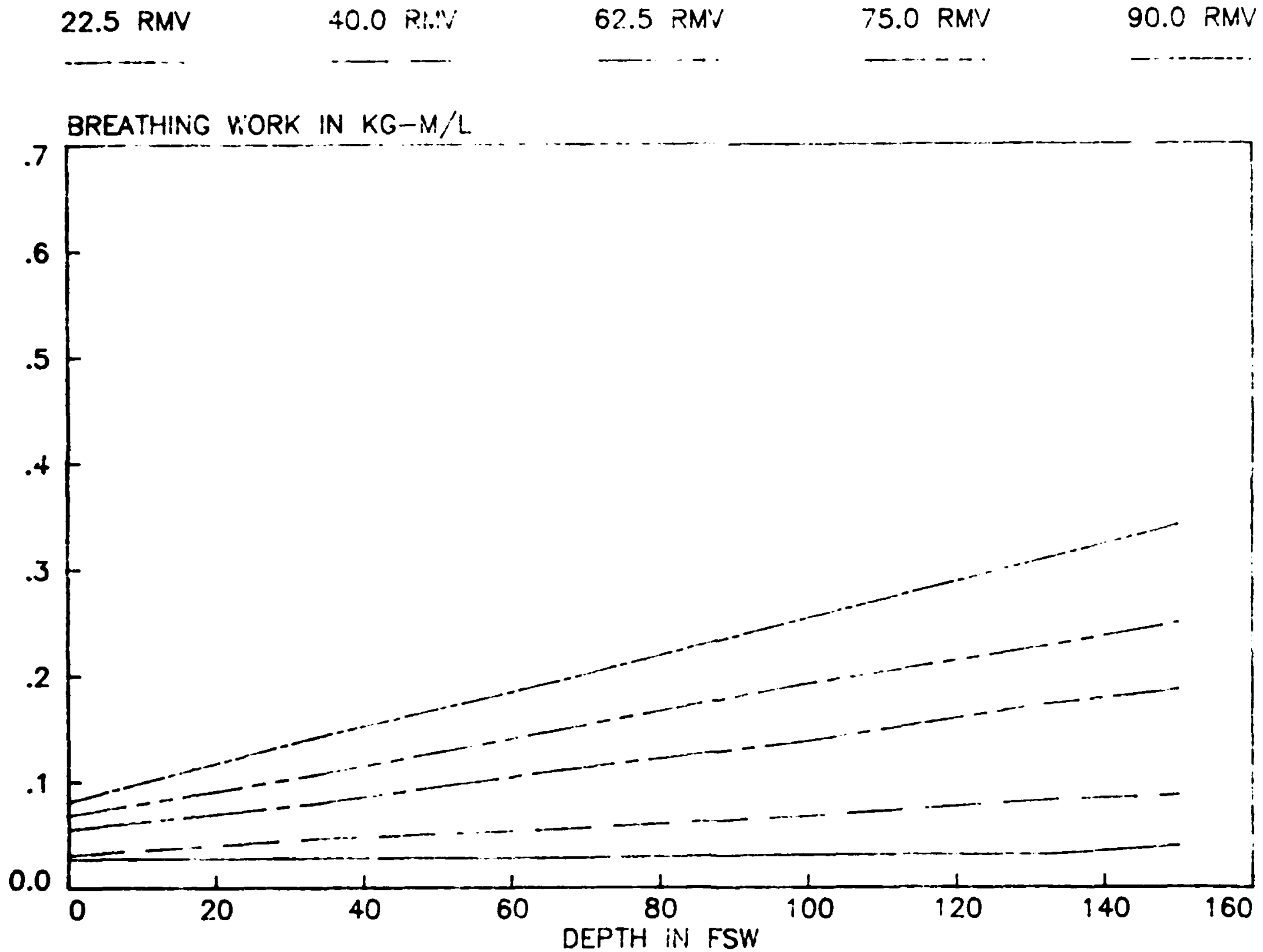


FIG.18 BREATHING WORK VS. DEPTH

MK-15 WITH REXNORD PROTOTYPE MOUTHPIECE & MK-16 HOSES

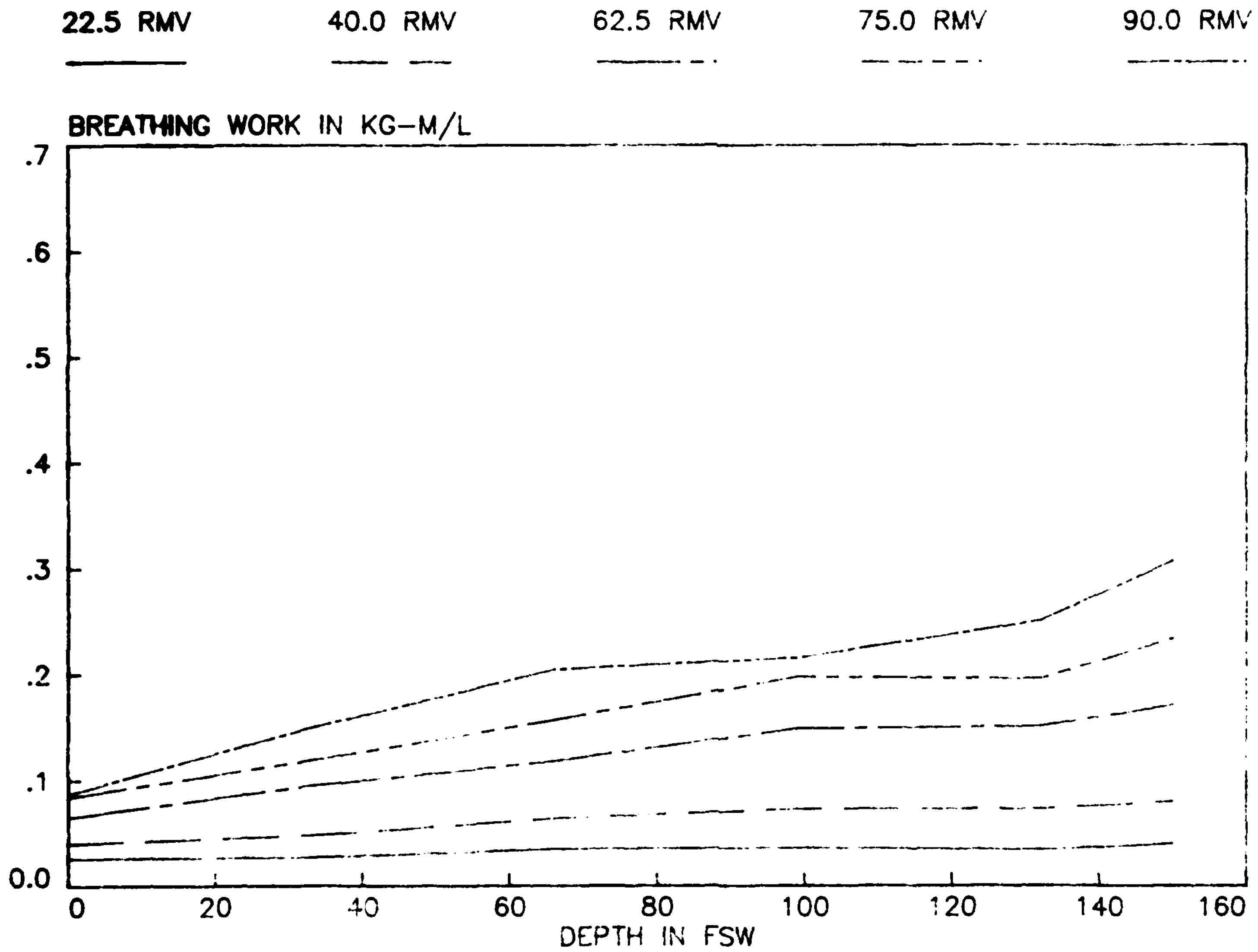
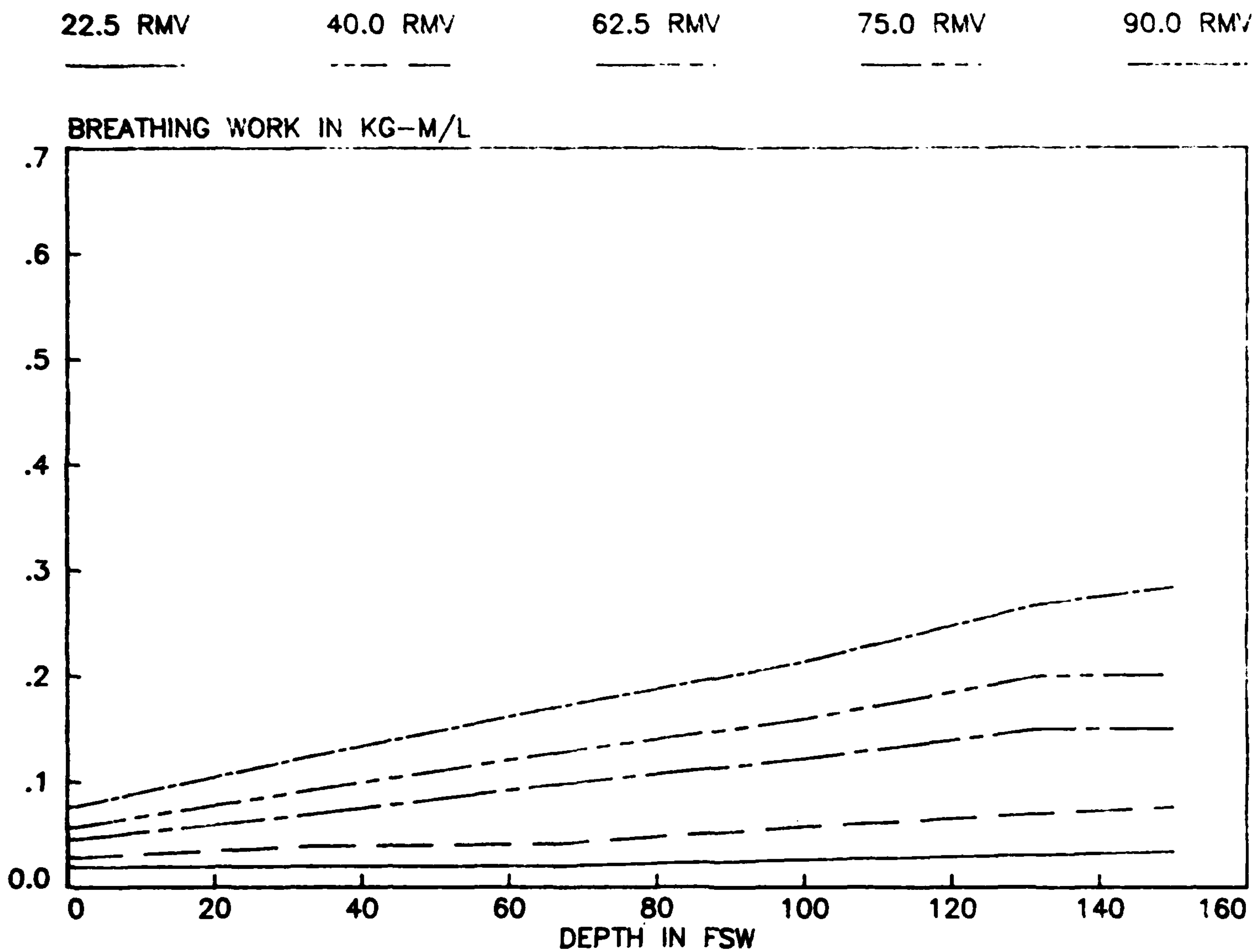


FIG.19 BREATHING WORK VS. DEPTH

MK-15 1/2 WITH REXNORD PROTOTYPE MOUTHPIECE & MK-16 HOSES



APPENDIX G

Canister Duration Data

Data for canister duration (% SEV vs time) is contained in this appendix for all six water temperatures tested. Effluent out of the canister was monitored during all tests to a level of 1.00% SEV and test results are plotted to this point on each graph. Canister breakthrough is considered to occur at 0.50% SEV. Data is gathered beyond this point to more fully examine the operational limits of the equipment.

KEY

Figure 20: Sample Graph of Raw Canister Duration Data

Figure 21: MK 15 1/2 UBA Canister Duration at 50 FSW in Water Temperatures Ranging from 29 to 90°F

FIGURE 20
UBA: CLOSED-CIRCUIT
WATER TEMP: 90'F
DEPTH: 50 FSW

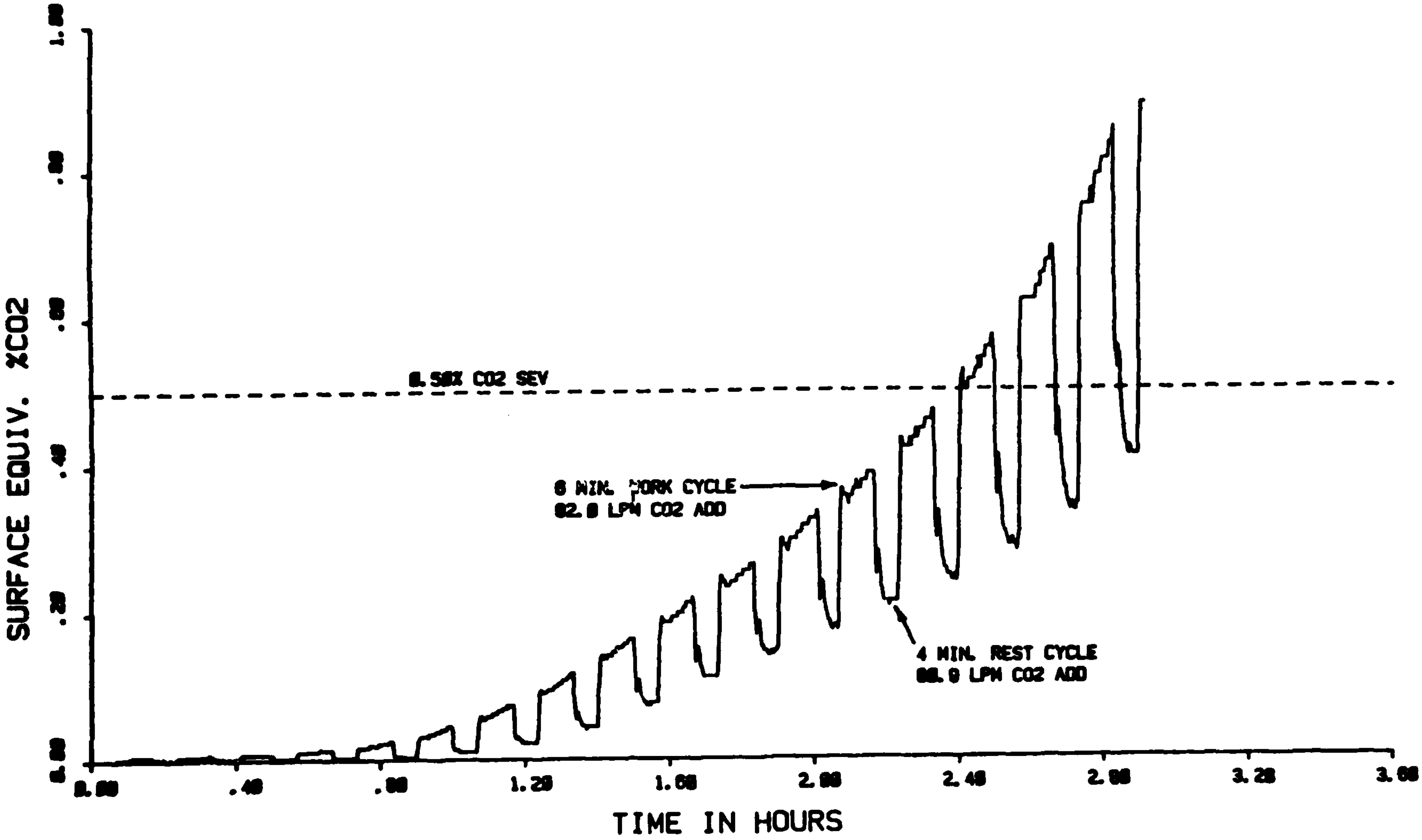


FIG.21 CANISTER DURATION MK-15 1/2 UBA AIR